WATER ELUTION OF ORGANIC MATTER IN THE NORTHERN TAIGA FORESTS OF THE KOLA PENINSULA

K. N. Manakov

Translation of "Vodnaya migratsii mineral'nykh elementov v severotayezhnykh landshaftakh Kol'skogo poluostrova," Pochvennye Rezhimy na Polyarnom Severe, edited by A. V. Baranovskaya, "Nauka" Press, Leningrad Branch, Leningrad, 1969, pp. 104-117

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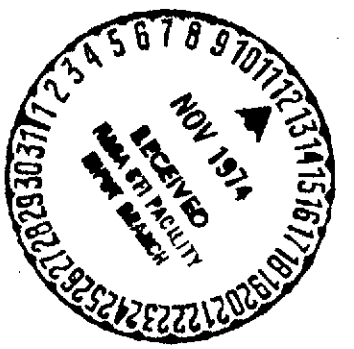

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16. Abstract

The unique conditions of the region are favorable for the water elution of inorganic matter. These are satisfactory amount of rain, good water penetrability of soil-forming rocks, and acid reaction of the acid solutions. These enable solution of the less mobile substances. The migration of inorganic matter eluted by water is partially retarded by an intensive biological assimilation. The eluvial regions are rich in eluted active elements, such as S, P, and Mn. The less active elements, such as Al, Fe, and Si, are present in the illuvial horizons. The biological use of S is very large and that of P, K, Ca, and Mg is not.

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WATER ELUTION OF INORGANIC MATTER IN THE NORTHERN TAIGA FORESTS OF THE KOLA PENINSULA

K. N. Manakov

The geochemical emphasis in the study of natural landscapes, whose foundations were laid by the country's outstanding geochemists V. I. Vernadskiy and A. Ye. Fersman, was formulated into an autonomous scientific discipline through the efforts of B. B. Polynov, who was the first to develop the basic premises and the methodology of studying geochemical features of landscapes.

The combined study of the chemical composition of soil-forming underlying rocks, groundwater, soils, and the vegetation growing thereon is of vital importance in understanding the soil-forming process. It is not fortuitous that soil scientists in the last decades have given greater attention to studying the recyling of matter between soil and vegetation. However, even upon a detailed study of biological recycling, often left out of consideration are important problems such as the migration of elements between elementary landscapes, while the history of each mineral element in the geochemical landscape is determined mainly by the ratio between its biological absorption and water elution.

The rate of the migration of elements within the landscape and between conjugate landscapes is influenced by numerous factors capable of intensifying or even weakening it. The main processes reducing the rate and intensity of the migration of chemical elements are these: 1) biogenic accumulation, that is, the selective absorption of specific elements by the vegetation from the soil and its biological accumulation of these elements on the surface and in the upper horizons of the soil after plants have died; 2) adsorption of elements by colloidal systems of the soil; and 3) precipitation of elements from solution into an insoluble residue at pH values that are specific for each element and each compound.

Through these processes, a given chemical element enters a low-active state, which then is the cause of the retardation of its migration in the landscape.

Factors accelerating the migration of a chemical element in a landscape are: 1) intensive mineralization of organic remains; 2) desorption of elements from colloidal system; and 3) dissolution of compounds when the soil solution becomes acidified.

Depending on the chemical properties of an element (valency and so on), as well as the natural conditions of landscape formation, the role of the above-listed processes in the migration of individual elements differs. Therefore characterizing the migration of an element in a landscape means establishing at each stage of migration the prevalence of retarding or accelerating factors (Perel'man, 1961). /105

In previous studies (Manakov, 1961, 1962a, and 1962b), we examined certain aspects of the biological recycling of mineral elements in geochemical landscapes of the northern taiga of the Kola Peninsula. In this article, an attempt is made to present the general pattern of the migration of the primary elements in landscapes based on theoretical considerations (Polynov, 1948, 1952; Lukashev, 1957; Perel'man, 1959, 1961; Rozhnova, 1962; Saukov, 1951, and so on), and to compare available data on the chemical composition of soils, soil-forming rocks, vegetation, and soil-ground water.

Fig. 1 presents a schematic profile of the conjugate geochemical landscape typical of the northern taiga of the Kola Peninsula. The dwarf black spruce, occupying the apex and the upper sections of the slopes of the moraine hill forms a zone of the eluvial (autonomous) elementary landscape. The soil profile is represented by illuvial-humic-ferruginous podzol, developed on a sandy, intensely boulder-covered moraine. Beneath a shallow layer (0-3 cm) of the forest litter (A_0) lies a well-formed whitish podzoic horizon, clearly replaced by chestnut-brown

illuvial horizon B, the upper part of which (B_1) differs from the lower (B_2) by dark color. In the zone of superaqueous (subordinate) landscape situated on the lower part of the slope of the same moraine hill, dwarf blue pine is developed on a peaty illuvial-humic podzol. The soil profile is characterized by relatively thick peaty sublayer (A_T), thin eluvial dirty-gray horizon A_2, and brown, relatively homogeneous leached horizon (B).

The northern taiga coniferous forests of the Kola Peninsula are characterized by overall reduced productivity of the vegetative biomass compared with the typical and southern taiga. In the northern taiga, shrub and lichen-moss cover exhibiting low ash content play a major role in the ground cover. Here soil formation is characterized by the predominance of illuvial-humic podzolic (eluvial landscapes) and podzolic-boggy (superaqueous landscapes) processes.

In northern taiga conditions, biological recycling is marked by the relatively low (in total quantity) involvement of mineral elements (capacity) and by moderate intensity, that is, by a small amount of mineral elements passing through the "living" form of matter in a specified time interval. At the same time, biological recycling is characterized by a relatively high rate of enrichment in certain elements that are most deficient in plants in biological cycles and by high competition between the involvement of these deficient elements in biological recycling and their removal from the domain of the landscape.

Owing to the high water permeability of soils light in mechanical composition and of soil-forming rocks, along with the relatively high level of atmospheric precipitation, in the forest landscapes of the Kola Peninsula intensive water elution of elements can occur both in ionic form as well as in the colloidal state together with easily soluble humic compounds. In these conditions the selective absorptivity of plants is a powerful factor counteracting the removal of active elements (sulfur, phosphorus, calcium, and so on) that are deficient in vegetation.

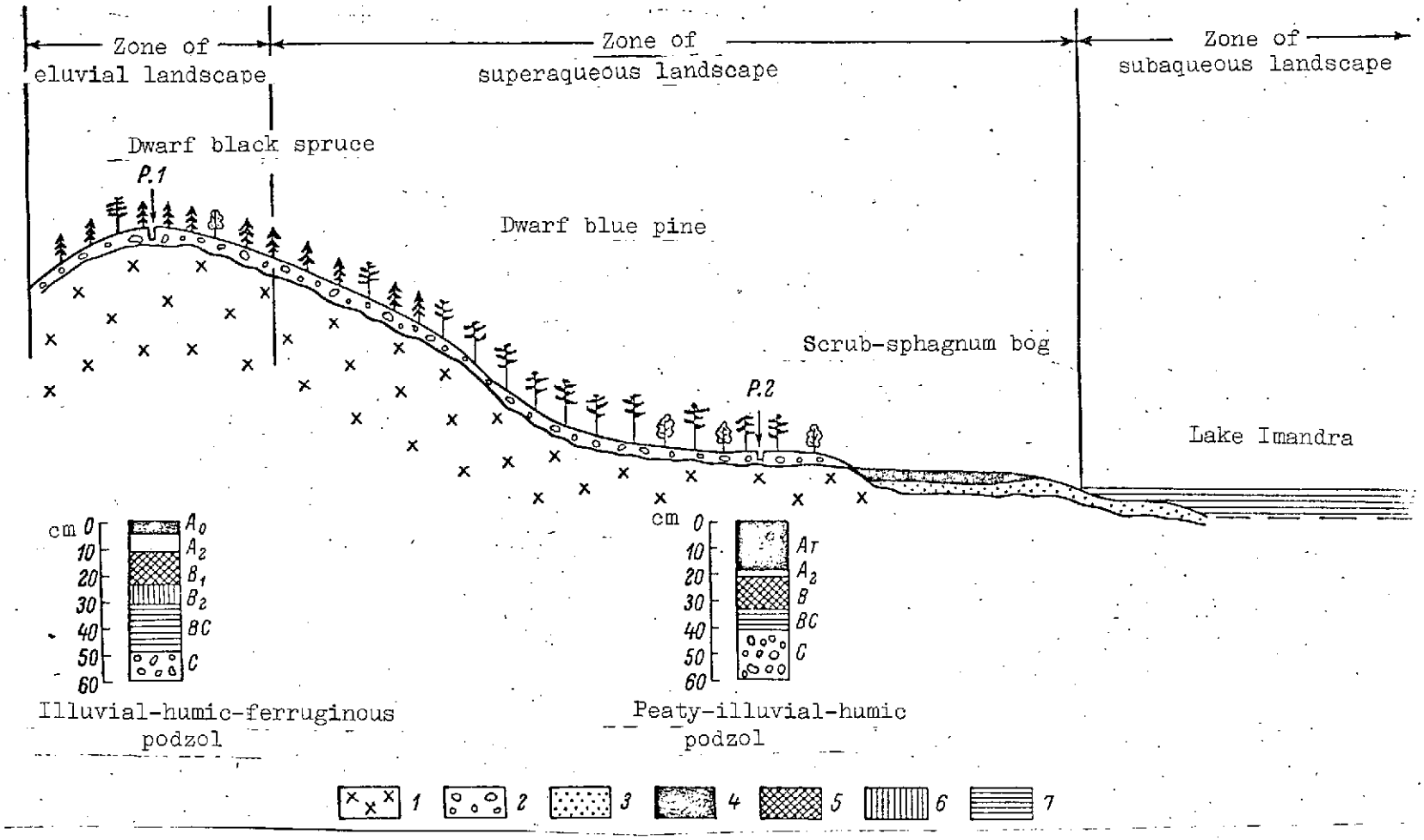

Fig. 1. Schematic profile of conjugate geochemical landscape in the area of the Apatity station

1. crystalline rock
2. primary moraine
3. lacustrine deposits
4. forest litter and peat beds
5. illuvial horizon P_1
6. illuvial horizon B_2
7. transitory horizon BC

At the same time the biological absorption of elements by plants enhances the migratory capacity of elements present in excess in /107
the landscape (silica, aluminum, and iron) by converting them into a more active form.

It is of interest to trace the behavior of individual chemical elements in eluvial and superaqueous landscapes as to their participation in biological recycling and water elution.

Silicon is an element that is fairly widely distributed in the earth's crust. The lithosphere in chemical composition is 87 percent quartz and silicates. In natural landscapes, silicon forms only oxygen compounds, which are very sparingly soluble in water. However, in northern taiga conditions the relatively active water elution of silica is observed. Soil-ground water (Table 1) contains it at the level of about 5-15 mg/liter. Silica is absorbed by vegetation in considerably smaller amounts compared with its content in soil. In the ash of plants growing in these northern taiga landscapes (Tables 5-6) its content is 9-13 percent. From this it can be concluded that the biogenic accumulation of silica is relatively low. However, certain plants (horsetails and cereals) and especially some parts thereof (spruce needle) contain considerable amounts of silica. In the ash of the above-ground section of plants, often more silica is present than in the roots (Table 2). Silicon unusually accumulates in the drooping parts of plants. With aging, the biogenic silicon returned to the soil surface with the leaf-fall reveals a marked mobility in the soil profile (Fig. 2). It has two accumulation maxima. The first maximum is in the lower part of the horizon of the forest litter where it is produced through the removal of the more active elements. Some of the active silicon migrates downward through the soil profile. This is indicated by the data of 5 percent KOH (Table 3) and oxalate (Table 4) extracts, which revealed the relatively high solubility of silica in the illuvial horizons. Some of the active silicon migrates into the zone of the superaqueous landscape, which is indicated by the presence of silicic acid in the soil-ground water

TABLE 1. CHEMICAL COMPOSITION OF SOIL-GROUND WATER (IN mg/liter) IN CONJUGATE GEOCHEMICAL LANDSCAPE

Sampling time	Mineral residue	SiO_2	R_2O_3	PO_4'''	Ca^{++}	Mg^{++}	Mn^{++}	$K^+ + Na^+$	SO_4''
Eluvial landscape									
Spring collection 1958	26.2	7.1	2.4	0.1	4.6	1.8	Traces	3.8	1.6
» » 1959	31.4	9.3	3.1	Traces	5.8	2.0	0.1	4.1	2.4
Superaqueous landscape									
Spring collection 1958	44.8	13.4	1.6	0.3	9.4	3.2	0.6	4.9	3.1
» » 1959	58.9	15.4	Traces	0.1	12.1	3.0	0.3	6.6	Traces
Autumn collection 1958	24.5	7.0	Traces	Traces	6.8	2.1	0.1	3.6	Traces
» » 1959	28.4	5.4	1.2	Traces	4.3	1.4	Traces	2.1	Traces

TABLE 2. ASH COMPOSITION OF ROOT MASSES IN INDIVIDUAL SOIL HORIZONS (IN PERCENT OF PURE ASH)

Object of analysis	Pure ash, % of dry plant	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	CaO	MgO	MnO	K_2O	Na_2O	SO_3	Molecular ratios		
												$SiO_2 : Al_2O_3$	$SiO_2 : Fe_2O_3$	$Al_2O_3 : Fe_2O_3$
Eluvial landscape (illuvial-humic-ferruginous podzol)														
Roots, horizon A_0	1.10	6.13	5.00	1.30	9.44	26.26	7.44	4.57	21.26	1.38	7.78	2.1	1.8	6.1
» horizon A_2	1.25	6.76	13.20	2.61	7.91	21.14	8.20	4.92	20.82	1.40	4.31	0.9	0.8	8.1
» horizons B_1, B_2	1.67	6.53	29.18	5.16	8.46	18.17	8.01	2.17	13.13	1.25	3.16	0.4	0.3	8.9
Superaqueous landscape (peaty illuvial-humic podzol)														
Roots, horizon A_1	1.03	5.58	6.18	2.41	9.18	27.91	8.28	4.81	20.75	0.91	8.29	1.5	1.2	4.1
» horizon A_2	1.46	7.19	15.91	3.15	12.06	18.15	7.91	1.76	21.17	0.56	7.19	0.8	0.7	7.8
» horizon B	2.13	7.31	32.16	4.82	5.97	11.78	8.56	2.02	12.96	1.03	6.18	0.4	0.4	10.5

TABLE 3. DATA FROM AN ANALYSIS OF 5 PERCENT KOH EXTRACT

Horizon	Sampling depth, cm	Total of extr. subst.	SiO_2	Al_2O_3	SiO_2	Al_2O_3	$SiO_2 : Al_2O_3$
		% of dry soil			mg-eq of dry soil		
Eluvial landscape (illuvial-humic-ferruginous podzol)							
A_2	5—10	0.85	0.83	0.02	13.8	0.20	69.0
B_1	15—20	3.80	1.01	2.79	16.8	27.4	0.6
B_2	25—30	2.67	0.86	1.81	14.3	27.6	0.5
BC	35—40	0.71	0.40	0.31	6.7	3.0	2.2
C	95—100	0.76	0.50	0.26	8.3	2.6	3.2
Superaqueous landscape (peaty-illuvial-humic podzol)							
A_2	18—21	0.80	0.36	0.54	6.0	5.3	1.1
B	25—30	1.49	0.56	0.93	9.3	9.1	1.0
BC	35—40	0.54	0.26	0.28	4.3	2.7	1.6
C	75—80	0.42	0.23	0.19	3.8	1.9	2.0

TABLE 4. DATA FROM AN ANALYSIS OF OXALATE EXTRACT

Horizon	Sampling depth, cm	SiO_2	Al_2O_3	Fe_2O_3	SiO_2	Al_2O_3	Fe_2O_3	Molecular ratios		
		% of dry soil			% of gross content			$SiO_2 : Al_2O_3$	$SiO_2 : Fe_2O_3$	$Al_2O_3 : Fe_2O_3$
Eluvial landscape (humic-ferruginous podzol)										
A_2	5—10	0.07	0.10	0.02	0.09	0.85	1.12	1.2	1.1	7.5
B_1	15—20	0.63	3.30	0.28	0.97	22.01	8.86	0.3	0.3	18.4
B_2	25—30	0.47	1.20	0.10	0.66	8.53	3.46	0.7	0.6	18.6
BC	35—40	0.11	0.78	0.07	0.15	5.26	2.61	0.2	0.2	17.4
C	95—100	0.06	0.42	0.04	0.08	2.99	2.00	0.2	0.2	16.5
Superaqueous landscape (peaty illuvial-humic podzol)										
A_2	18—21	0.05	0.48	0.06	0.07	3.42	1.41	0.2	0.2	12.4
B	25—30	0.04	0.56	0.08	0.06	3.78	1.54	0.1	0.1	11.0
BC	35—40	0.06	0.46	0.08	0.09	3.05	1.59	0.2	0.2	9.0
C	75—80	0.06	0.43	0.07	0.09	2.79	1.47	0.5	0.2	9.6

(Table 1). It is probable that some of the silicic acid is leached from the aluminosilicates of the parent rock and also migrates into the superaqueous landscape.

As shown by the data of oxalate extracts (Table 4), the solubility of silica is considerably inferior to the solubility of the sesquioxides. The recycling of silicon between soil and vegetation in conditions of the superaqueous landscape is marked by a smaller volume of its absorption and returns to the soil than in the eluvial landscape. Much of the silica departs beyond the limits of the superaqueous landscape with the groundwater (10-15 mg/liter). This is also confirmed by data of oxalate and alkaline extracts (Tables 3 and 4), showing that in peaty illuvial-humic podzol, the content of active silicic acid is considerably less than in the illuvial-humic-ferruginous podzol of the eluvial landscape.

Thus, silica is the least active of all the elements we are studying. In the eluvial landscape the biological recycling of silicon proceeds more intensively than in the superaqueous landscape. Some of the silicon makes a transit through the superaqueous landscape and migrates with groundwater into the zone of the subaqueous landscape and then into streams and lakes. Living organisms in the landscapes are fully provided with silicon, therefore the vegetation, in addition to the amount it requires, absorb most of the silicon as an ecological admixture and then return it with the leaf-fall without significant use in biochemical processes. However, on being absorbed by plants and thus participating in the biological recycling, the silicon somewhat slows down its migration. As we can see from the foregoing, typical of silica is some biogenic accumulation, a considerable precipitation of insoluble compounds, and a negligible role of mineralization and dissolution. The silicon in the landscape is characterized by relatively weak lability. /110

Aluminum is the most widely distributed element in the earth's crust. In the landscapes we are studying it can be present in the

trivalent form. However, being an ampholytoid, aluminum has a variable valency, forming salts of aluminosilicic acid (aluminosilicates). Precipitation in the form of the hydroxide (at pH 3.3-4.0) retards the possibility of its water elution. However, complex compounds of aluminum with fulvic acids are very active (a precipitate at pH 4.5-5.0).

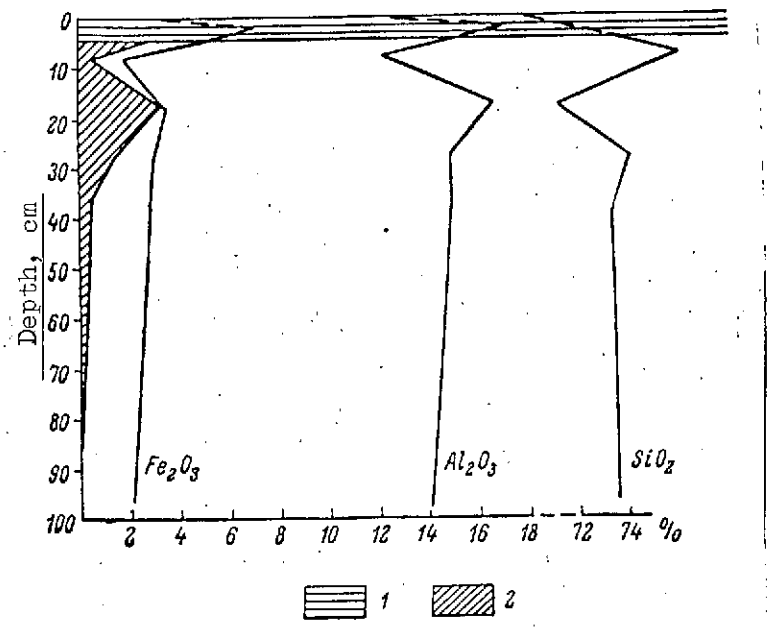

Fig. 2. Distribution of humus, sesquioxides, and silica over the profile of illuvial-humic-ferruginous podzol (eluvial landscape)
1. forest litter
2. humus

Aluminum is absorbed by vegetation in relatively high quantities (it averages 5 percent of pure ash). Plant roots are marked by a significant aluminum content. In particular, much aluminum is absorbed by roots from the horizons A_2 and B (up to 30 percent of pure ash). Much aluminum is accumulated by the green parts of plants, however before the leaf-fall it migrates into the stump and roots.

Evidently, aluminum departs from the biological recycling in two pathways: when root masses containing most of it die, and also in the leaf-fall. It is wholly probable that the first pathway is highly significant, however this has not yet been experimentally confirmed.

There are data (Remezov, 1959) indicating that some of aluminum is released from living roots during the autumn period. A considerable amount of aluminum is accumulated upon the decomposition of

the forest leaf-fall, especially the lower part of the well-decomposed forest litter (Table 5). The maximum accumulation of aluminum is observed in the illuvial horizon of the soil, into which it migrates and becomes combined with organic acids (Fig. 3). Its high activity within the limits of the soil profile can be judged from the data of alkaline and oxalate extracts (see Tables 3 and 4). The activity of aluminum in underlying horizons is relatively low. Some aluminum is present in groundwater, but in all probability its displacement from the sphere of the eluvial landscape occurs mainly in a complex with fulvic acids. However, active compounds of aluminum are easily retained in the horizon of the forest litter, and also in the illuvial horizons, where a maximum humus accumulation is observed when there is a weakly acidic reaction of the soil solution (Figs. 1 and 2). It is also highly probable that aluminum migrates in particles of aluminosilicates present in a suspended state in the soil-ground water when the water undergoes a considerable elevation, especially in spring during the thawing of snow. From the domain of the superaqueous landscape aluminum evidently migrates more intensively, which is indicated by the low content of soluble Al_2O_3 in the oxalate extract of the peaty podzol (Table 4). /111

Thus, aluminum in the landscapes investigated is marked by a relatively high biogenic accumulation and by the ability to precipitate in the form of poorly soluble compounds. The role of processes enhancing migration is slight, however some of it probably can migrate in a complex with fulvic acids (Ponomareva, 1951). The relatively high aluminum content in plants of the north is possibly associated with the calcium deficiency.

Iron. The migration of iron in the landscape is due to its different valency. Bivalent iron precipitates even at pH 6.5-7.5; it easily migrates in the forms $Fe(HCO_3)_2$ and organo-iron compounds. However, bivalent iron is unstable and when free oxygen is present it rapidly passes into the trivalent state, which produces nearly no soluble mineral compounds, precipitating at pH 2.3-4.1. Much of /112

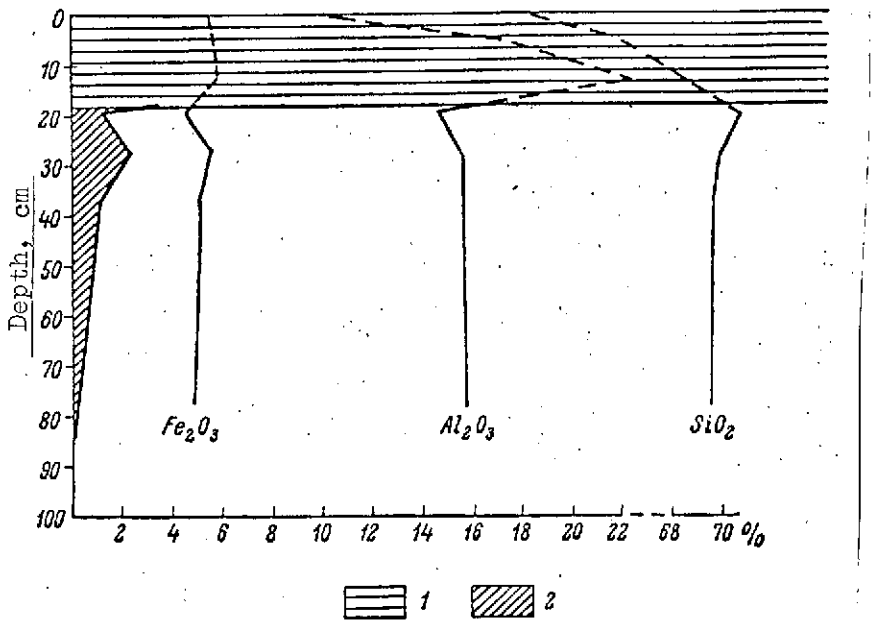

Fig. 3. Distribution of humus, sesquioxides, and silica over the profile of peaty illuvial-humus podzol (superaqueous landscape)
1. forest litter
2. humus

the trivalent iron is present in colloidal complexes with fulvic acids (Ponomareva, 1951), which can easily migrate with soil-ground water.

Iron, like aluminum, is intensively absorbed by roots. In plants iron places an important physiological role, by influencing the formation of chlorophyll and also participating in other oxidation-reduction processes, being present in numerous enzymes.

Some increase in the amount of iron occurs in the deciduous parts of plants. On falling with leaf-fall on the soil surface, it accumulates in the lower part of the forest litter horizon. The narrower ratio of the oxides Al_2O_3:Fe_2O_3 in the litter shows that the accumulation of iron occurs more intensively than for aluminum. This has also been noted in illuvial soil horizons (Figs. 2 and 3). The fixation of iron in horizon B together with the organic matter slows down the migration of this element from

the domain of the eluvial landscape. There is considerably less active iron in the superaqueous landscape than in the eluvial, which is indicated by oxalate extract.

Evidently, active iron in combination with organic acids to a large extent migrates in soil-ground water into the nearest bog.

Thus, the migration of iron is affected by all the factors that reduce it: biological accumulation, precipitation, and adsorption by soil colloids. In contrast to aluminum, ferrous iron is characterized by higher solubility, therefore the possibility of the water elution of this element is higher, especially in the superaqueous landscape. Vital in increasing the migration of iron is its ability to form active colloidal complex organo-mineral compounds with fulvic acids. Iron migrates more actively in the superaqueous landscape than in the eluvial.

Phosphorus. In the landscapes of the northern taiga, phosphorus is usually present in the pentavalent form as insoluble salts of orthophosphoric acid. They are formed from different forms of calcium phosphate, principally from apatite. Phosphorus is present in soil in a small concentrations -- only 0.2-0.3 percent.

Plants intensively absorb phosphorus and, in view of its deficiency, evidently utilize phosphorus continuously; before leaf-fall there is an intensive outflowing of phosphorus to the green storage parts of the plants, therefore relatively little phosphorus leaves in the leaf-fall. There are also indications that phosphorus can be leached from living leaves by rain water (Remezov, 1959).

Upon the decomposition of the leaf-fall, phosphorus is rapidly released, but is incapable of being significantly washed out of the forest litter, since it is rapidly captured by microorganisms and plant roots and again is involved in biological recycling.

However, the somewhat increased phosphorus content in the spring in groundwater indicates that during this period it can migrate to the zone of the superaqueous landscape and precipitate, by being adsorbed by the colloids of iron and aluminum.

TABLE 5. ASH AND GROWTH COMPOSITION OF VEGETATION AND SOIL IN DWARF BLACK SPRUCE /ELUVIAL LANDSCAPE (IN PERCENT OF CALCINED MASS)/

Object of analysis из	Sampling depth, cm	Pure ash % of dry plant	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	CaO	MgO	MnO	K_2O	Na_2O	SO_3	Molecular ratios		
													$SiO_2 : Al_2O_3$	$SiO_2 : Fe_2O_3$	$Al_2O_3 : Fe_2O_3$
Vegetation:															
above-gr. part	—	0.82	13.90	5.24	1.10	8.05	29.63	7.68	3.90	16.83	2.07	6.46	4.5	4.0	7.3
roots	—	1.17	6.32	9.57	1.97	9.06	24.36	6.84	4.36	20.34	1.37	6.50	1.1	1.0	7.8
leaf-fall	—	2.70	23.19	4.78	1.26	4.81	33.81	6.81	3.70	8.33	1.30	6.59	8.2	7.0	5.9
Forest litter															
A_0	0—1	2.21	22.91	10.97	2.39	6.15	27.81	8.11	5.14	7.96	2.19	3.42	3.5	3.1	7.2
A_0	1—4	3.14	31.98	17.01	6.99	2.51	18.12	4.96	3.24	5.35	1.20	1.85	3.1	2.5	3.8
Soil															
A_2	5—10	98.15	77.98	12.03	1.82	0.11	2.05	0.93	0.05	2.11	1.03	0.04	11.0	10.1	9.2
B_1	15—20	91.05	71.17	16.46	3.47	0.29	4.06	1.18	0.09	2.87	1.23	0.10	7.3	6.5	7.3
B_2	25—30	94.75	74.17	14.84	3.05	0.31	3.65	1.10	0.08	2.36	1.30	0.12	8.5	7.5	7.7
BC	35—40	99.10	73.29	14.94	2.70	0.27	3.28	1.65	0.07	2.17	1.89	0.09	8.3	7.4	9.0
C	95—100	99.27	73.61	14.14	2.01	0.21	3.17	1.57	0.08	2.11	1.57	0.08	8.8	8.0	10.1

TABLE 6. ASH AND GROWTH COMPOSITION OF VEGETATION AND SOIL IN DWARF BLUE PINE /SUPERAQUEOUS LANDSCAPE (IN PERCENT OF CALCINED MASS)/

Object of analysis	Sampling depth, cm	Pure ash % dry plant	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	CaO	MgO	MnO	K_2O	Na_2O	SO_3	Molecular ratios		
													$SiO_2 : Al_2O_3$	$SiO_2 : Fe_2O_3$	$Al_2O_3 : Fe_2O_3$
Vegetation															
above-gr. part	—	0.75	9.33	4.27	1.20	7.20	34.53	8.53	3.73	17.73	1.83	7.07	3.7	3.1	3.5
roots	—	1.03	5.87	8.62	2.66	9.08	26.24	8.26	4.50	20.18	0.83	8.07	1.1	1.0	5.0
leaf-fall	—	3.11	10.68	3.92	1.99	5.21	39.74	6.98	2.89	14.98	1.00	7.11	4.7	3.6	3.2
Forest litter															
A_T'	0—3	6.84	18.91	11.64	5.40	3.60	33.62	5.45	2.28	6.93	1.60	6.03	2.8	2.1	3.4
A_T''	3—8	6.10	21.83	17.55	5.59	2.95	22.38	4.74	2.95	5.05	1.34	2.06	2.1	1.8	4.9
A_T'''	8—18	8.57	26.28	22.21	5.64	0.85	18.51	2.70	0.84	3.78	0.54	1.33	2.1	1.4	2.2
Soil															
A_2	18—21	96.65	70.55	14.54	4.41	0.27	3.81	1.54	0.08	2.67	1.16	0.06	8.24	6.87	5.11
B	25—30	95.32	69.88	15.54	5.47	0.37	4.02	1.83	0.12	2.84	1.01	0.07	7.63	6.26	4.47
BC	35—40	97.40	69.43	15.46	5.15	0.38	3.21	1.66	0.09	2.63	1.16	0.08	7.62	6.28	4.75
C	75—80	97.95	69.54	15.75	4.87	0.31	3.61	1.49	0.08	2.48	1.08	0.07	7.49	6.23	5.00

Thus, in the migration of phosphorus biogenic accumulation is of predominant importance, retarding its removal from the domain of the landscape. The dissolution and removal of phosphorus by groundwater during the spring period is of some significance.

Calcium. The total calcium content in the biomass of plants and soils of this landscape is quite high. Calcium is contained in soils and soil-forming rocks in the amount of 2-3 percent (Tables 5 and 6), but evidently is present in feldspars in the insoluble /114 state. Most of the active calcium is contained in the forest litter. The vegetation intensively absorbs calcium, since it participates strongly in the nitrogen exchange of plants. Before the leaf-fall, its content in the leaves and needles increases. Leaf-fall causes the biogenic accumulation of calcium in the litter. Some of the biogenic calcium is rapidly leached from the leaf-fall and migrates downward across the soil profile, being fixed in the absorbed state in the illuvial horizons. Some of the calcium /up to 6 mg/liter (Table 1)/ is to be found in soil water. This indicates the possibility of water elution of calcium from the domain of the eluvial landscape in the ionic state. However, the undersaturation of the absorbing soil complex inhibits its removal from the domain of the landscape.

Thus, characteristic of calcium is high biogenic accumulation, and in view of this it is a deficient element in the phytocenosis. The possibility of water elution of readily soluble calcium compounds therefore is strongly limited, although this does take place in the spring period before the growing season. Calcium is an important biogenic element and at the same time a good water migrant. Most of the active calcium is in continuous biological recycling between the forest litter and the individual tiers of vegetation in time-different cycles (mainly perennial) and is not removed from the landscape.

Magnesium. In its chemical properties, magnesium is akin to calcium, however its overall content in the weathering crust

as a whole is considerably less. The coefficient of biological absorption of magnesium is less than for calcium.

Magnesium is rapidly leached from the leaf-fall, however its water elution is restricted by the fact that it is strongly combined with the absorbing complex; the remaining portion of active calcium enters into the composition of low-soluble secondary silicates or is absorbed again by plants.

Thus, magnesium is a biogenic element that is less active than calcium, and a more active water migrant. As a result, the depletion of the upper horizons by magnesium occurs earlier than the removal of calcium.

Potassium. In soil-forming rocks, potassium is present for the most part in aluminosilicates, in orthoclase, microcline, and mica. Characteristic of calcium is the formation of soluble compounds with the anions of nitric, hydrochloric, sulfuric, phosphoric, and other acids.

Potassium is one of the most important biogenic elements. On being absorbed by plants, it participates in water, carbon, and nitrogen exchange, intensifies the processes of photosynthesis, increases the water content of plasma colloids, and increases the cold hardiness of plants.

Before the leaf-fall, potassium migrates from the deciduous parts and is reutilized by plants. Some of the potassium falling onto the soil in the leaf-fall is rapidly leached and is reutilized by the microorganisms and plants. No considerable accumulation of potassium in illuvial horizons is observed. It is adsorbed by colloidal systems and can enter into the structure of secondary minerals. Therefore potassium is a weak water migrant. Nearly all of the active potassium is in biological recycling.

Sodium in soil-forming rocks is present as part of feldspars, nephelin, amphiboles, and other minerals.

Its compounds are easily soluble in natural water. However, it is slowly leached from stable primary minerals. Compared with other elements, potassium is weakly absorbed by plants, but participates in numerous physiological processes, and particular, it /115 promotes the translocation of carbohydrates in plants.

Sodium is easily leached from the leaf-fall and is removed in groundwater from the landscape into the nearest bodies of water.

Thus, sodium is characterized by a low quantitative participation in biological recycling and by intensive water elution.

Manganese is characterized by variable valency. In the northern taiga landscape manganese is present mostly in the bivalent form and is easily accessible to plants, since it forms readily soluble compounds.

Thus, $Mn(OH)_2$ precipitates at pH 7.8-8.8 and therefore is not encountered in acidic soils of the taiga zone in the undissolved form. Tetravalent manganese forms virtually insoluble compounds.

Bivalent manganese in the conditions of the north is very intensively absorbed by plants and accumulates in the needles and shrub (dwarf black spruce and dwarf blue pine).

Manganese plays a major role in the physiological processes of plants, chiefly oxidation-reduction. It participates also in the assimilation of nitrogen, respiration, and photosynthesis.

Before leaf-fall, the manganese content in needles and leaves decreases. Much manganese is contained in the roots. In the litter its content decreases sharply with depth. The mineral soil horizons contain hundredths of a percent of manganese. Manganese is present in soil-ground water in a slight amount (up to 0.1 mg/liter). The possibility of water elution of manganese is severely limited owing to its absorption by vegetation and precipitation as insoluble compounds.

Thus, manganese is an active participant in biological recycling, which limits its possibility of migrating in soil-ground water.

The reasons for the increase in manganese content in plants in the Polar North are as yet unclear. There are grounds to assume that it replaces Ca and Mg when they are deficient in the landscape.

Sulfur. In the eluvial landscapes sulfur predominates in the hexavalent form. In the superaqueous conditions, especially in bogs, sulfur can be reduced and is found in the bivalent state as hydrogen sulfide, various sulfides, and inorganic compounds. Owing to the variable valency of sulfur, highly significant in its migration are oxidation-reduction processes (especially microbiological).

In the mineral horizons of soil, sulfur is present in slight amounts. It is rapidly leached from decomposing leaf-fall by atmospheric precipitation, recaptured by plants, and involved in biological recycling. Sulfur is partially removed by groundwater in depressions, especially in spring, after the thawing of snow when plants as yet weakly utilized it.

Thus, sulfur along with phosphorus, manganese, and potassium is an active participant in biological recycling. Favorable conditions for water elution of sulfur lead to its deficiency in eluvial landscapes and its accumulation in bogged depressions of the relief with the formation of sulfides and hydrogen sulfide.

Nitrogen. In spite of the enormous content of nitrogen in the atmosphere, it is an element that is extremely deficient for plants.

Water elution of mineral forms of nitrogen has limited significance. The vital activity of organisms (biological recycling) /116 has the predominant effect on the conversion of nitrogen. Its fixation from the atmosphere and its transformation into mineral forms occurs as the result of microbiological processes, which cannot be examined in our study. The role of nitrogen in biological recycling thus far cannot be illuminated adequately.

Nitrogen is very intensively absorbed by vegetation. In most plants studied in both landscapes, its content is as high as 1 percent on a dry matter basis, that is, plants contain more nitrogen than any of the other elements we have examined. There is less nitrogen present in leaf-fall than in living leaves and needles. With slow decomposition of the leaf-fall, much nitrogen accumulates in the organic form in the forest litter horizon. As a result of microbiological processes, organic nitrogen is gradually converted into the mineral form (nitrates and nitrites). These compounds are easily soluble, however water elution of nitrogen in the conditions of the Polar North usually does not occur. Most of the mineral nitrogen formed through microbiological processes is gradually absorbed by the vegetation, which can use almost no nitrogen in the organic forms. Therefore it is always a deficient element for most plants in both landscapes. Data have been reported indicating that some nitrogen enters soil with atmospheric precipitation. Thus, in a paper by Boritskaya (1962), data are given stating that in the conditions of the Kola Peninsula about 5.5 kg of nitrogen per hectare per year comes with atmospheric precipitation. This amount cannot provide plants with their assimilable nitrogen. According to our data, the amount of nitrogen arriving into the soil in leaf-fall is 11.8 kg/hectare per year in the eluvial landscape, and 17.7 kg/hectare /per year/ in the superaqueous landscape.

The processes of the biological fixation of atmospheric nitrogen in the conditions of the Kola Peninsula have been nearly totally investigated. But there is no doubt that these processes play an essential role in the accumulation and migration of nitrogen.

Conclusions

1. In the distinctive conditions of the northern taiga of the Kola Peninsula favorable conditions exist for the water elution of mineral elements: an adequate influx of atmospheric precipitation

into the landscape, good water permeability of the soil-forming rocks, and acidic reaction of the soil solutions, promoting the dissolution of low-active compounds.

2. A powerful factor counteracting the water elution of active elements, but even deficient supply for plants, is the intense biological absorption of substances by organisms. At the same time the vital activity of organisms promotes the migrating ability of elements present in excess by converting them through absorption in the form of an admixture to a more active state.

The role of biological absorption as the primary factor retarding the removal of elements from the domain of the landscape is manifested selectively for different elements: the more deficient an element is for plants, the more rapidly it is involved in biological recycling.

3. In the eluvial landscapes, the most active migrants -- sulfur, phosphorus, and manganese -- are present in continuous biological recycling in the system litter-vegetation-leaf-fall.

The less active migrants -- aluminum, iron, and, partially, silicon -- reveal marked activity in the soil profile, being accumulated in the illuvial horizon and the lower layers of the forest litter.

As a result of the washing out elements from the domain of /117
the eluvial landscape and their involvement in biological recycling, an eluvial horizon is formed in which the content of active migrants reaches a minimum.

4. The movement of elements in the superaqueous landscapes is characterized by the influx with soil-ground water of some amounts of the elements from the eluvial landscape and the periodic removal to the nearest depressions. In spite of the high mobility of elements in the superaqueous landscapes, the mass of the active migrants in the landscapes is higher and vegetation succeeds in

more readily involving them in biological recycling. Therefore the load on biological recycling in superaqueous landscapes is considerably weaker than in the eluvial landscapes and approaches the middle-taiga conditions.

5. As to their participation in biological recycling and water elution in the northern taiga landscapes of the Kola Peninsula, some elements are characterized thusly: sulfur is marked by the most active participation in biological recycling, as well as in the water elution of elements; phosphorus, potassium, calcium, and magnesium, as well as manganese generally are present in biological recycling and weakly participate in water elution; iron and sodium are characterized by relatively weak participation in biological recycling and actively migrate from the domain of the eluvial landscapes; both participation in biological recycling as well as water elution is observed in the movement of silicon; aluminum relatively weakly participates in biological recycling and manifests considerable mobility, by participating in the water elution of elements.

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